On the Nature of Emergent Reality

George F R Ellis

"If the human [soul] is anything, it must be of unimaginable complexity and diversity [...] . I can only gaze with wonder and awe at the depth and heights of our psychic nature. Its non-spatial universe conceals an untold abundance of images which have accumulated over millions of years of living development and become fixed in the organism. My consciousness is like an eye that penetrates to the most distant spaces, yet it is the psychic non-ego that fills them with nonspatial images. And these images are not pale shadows, but tremendously powerful psychic factors… Beside this picture I would like to place the spectacle of the starry heavens at night, for the only equivalent of the universe within is the universe without; and just as I reach this world through the medium of the body, so I reach that world through the medium of the psyche."

- C. G Jung (Freud and Psychoanalysis, CW 4, p. 331)[1]

1. Broad Theses on Emergent Reality

1.1 The Hierarchy of physical structure and causation.

Emergence of complex structures, including conscious life, from simpler physical structures is based in tightly structured non-linear relations between components, designed to produce specific higher level functioning. This emergence of higher level structuring is captured in the structural and causal hierarchy (Peacocke 1983, Campbell 1991, Murphy and Ellis 1995, Scott 1995) shown in Figure 1.

The Hierarchy of Structure

Sociology/Politics/Economics
Animal Behaviour/Psychology

Botany/Zoology/Physiology
Cell Biology

Biochemistry/Molecular Biology
Molecular
Chemistry
Atomic Physics
Nuclear Physics

Particle physics

Figure 1: The hierarchy of structure and causation for living systems, characterized in terms of the corresponding academic subjects.

Each higher level, created by structured combinations of lower level elements, has different properties from the underlying lower levels - the entities at each level show behaviours characteristic of that level. There is a vast variety of existence at each higher level in the hierarchy (very large numbers of possible organic macromolecules, very many species of animals, etc), but fewer kinds of entities at the lower levels (atoms are made just of protons, neutrons, and electrons), so complex objects with complex behaviour are made by highly structured combinations of simpler objects with simpler behaviour. Each level underlies what happens at the next higher level, in terms of physical causation. The existence of higher level complex

[1] From http://www.JourneyintoWholeness.org/news/nl/v11n3/index.shtm

behaviour, which does not occur at the lower levels, then emerges from the lower level properties both structurally and functionally (at each moment) and in evolutionary and developmental terms (over time).

1.2 Theses on Emergence

In this paper I first give some broad statements on the nature of emergence in this section, and then elaborate on some of them in the following sections.

1. Emergence is different in different contexts. It is useful to look at the variety of complex systems (Ellis 2002) to see its different aspects: (a) *Natural objects* (non-living), (b) *Living beings* (including conscious beings) (Campbell 1991, Scott 1995), (c) *Manufactured objects* (artefacts), particularly computer systems (Tannenbaum 1990).

The different kinds of emergence corresponding are discussed in Section 5 below. This paper mainly concentrates on the highest level of emergence – self-conscious human beings.

2. Emergence is characterised by hierarchical structures with different levels of order and descriptive languages (levels of phenomenology), plus a relational hierarchy at each level of the structural hierarchy. The structural hierarchy is indicated in Figure 1. Note that one can't even describe higher levels in terms of lower level languages; a different phenomenological description of causation is at work at the higher levels, which may be described in terms of different causal entities[2]. The different levels of language are particularly clear in the case of computers and the genetic information coded in DNA.

One can't understand relations between the vast variety of objects at each higher level without using a hierarchical characterisation of properties at that level, e.g.

"animal - mammal – domestic animal – dog – guard dog - Doberman - Fred",
"machine – transport vehicle - automobile – sedan – Toyota – CA687-455".

The characterisation used here may be based on (i) appearance, (ii) structure, (iii) function, (iv) location and/or history (e.g. evolutionary history), or (v) an arbitrarily assigned labelling (e.g. alphabetic or numeric order). Note that these categorisations go from the very generic to the individual/specific.

3. These hierarchical structures are modular – made up by structural combinations of semi-autonomous components with their own internal state variables, each carrying out specific functions. It is useful here to look at the case of computer systems (Tannebaum 1990) and object oriented languages (Booch 1994) for principles such as abstraction and inheritance underlying modularity. In general many lower level states correspond to a single higher level state, because a higher level state description is arrived at by averaging over lower level states and throwing away a vast amount of lower level information (`coarse graining'). The number of lower level states corresponding to a single higher level state determines the entropy of that state. This is lower level information that is hidden in the higher level view. In life, the crucial module is the cell (Harold 2001).

Binding is tighter and speeds of interaction and energies are higher at the lower levels of the hierarchy; combinations of many high-frequency lower-level interactions result in lower-frequency higher-level actions (a computer microchip may perform millions of operations per second; the user still has to wait for the computer to do what she wants at the macro level).

4. Emergence occurs in terms of (a) evolution of species/type, (b) development/creation of each individual object/being, and (c) function of individual object/being, each occurring with very different timescales. As life emerges, in each case there is a dramatic change from matter without complex functionality to living material. The relevant timescales (Figure 2) are related both to physical size and to degree of tightness of coupling. At the topmost level, each type of emergence is characterised by adaptive

[2] In terms of physics, we have macroscopic *effective theories* occurring (Hartmann 2001) that are the result of averaging over lower level causal relations, and that differ from the microscopic relations. For example in electromagnetism we have the difference between the electromagnetic field governing microphysics and the induction field governing macrophysics, related by the polarisation tensor – which is a measurable physical quantity.

selection in interaction with the physical and social environment, which are the boundary conditions for the system.

Timescales

Kind of System	*Long term Evolution*	*Short term Evolution*	*Development*	*Function*
Natural	10^9 yrs	10^5 yrs	10^5 yrs	hours-days
Biological	10^9 yrs	10^5 yrs	20 yrs	1msec
Artificial	10^4 yrs	10^2 yrs	10 yrs	1μsec

Figure 2: The different timescales associated with evolution, development, and functioning. In the `natural system' row, `function' refers to events such as volcanoes, earthquakes, typhoons, etc. In the `biological systems' row, it refers for example to typical brain operations, while in the `artificial systems' row it refers to a typical modern computer and its micro-operations.

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5. Emergence is enabled by the simultaneous operation of (a) bottom-up, (b) same level, and (c) top-down action, the latter two occurring by coordinating lower level actions according to the system structure and boundary conditions. Reliable higher level laws – the key requirement for meaningful higher level behaviour - occur if the variety of lower level states corresponding to a particular higher level state all lead to the same higher level action. Then the lower level actions may be coordinated by the higher level ones so that top-down action occurs and effects same-level action. This affects the nature of causality in an important way, because same level and inter-level negative and positive feedback loops become possible (Figure 3).

Bottom up and top-down action:

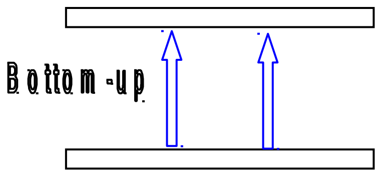

Figure 3a: Bottom-up only.

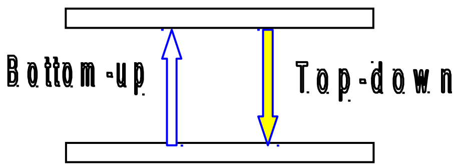

Figure 3b:
Bottom-up and Top-down.

Figure 3: Bottom-up and Top-down action. The fundamental importance of top-down action is that it changes the overall causal relation between upper and lower levels in the hierarchy of structure and organisation, cf. the difference between Fig 3a and Fig 3b.

Causality in coherent complex systems has all these dimensions (bottom-up, same level, top-down). For example (Ackoff 1999), the question: `Why does an aircraft fly?' can be answered

- In *bottom-up terms*: because air molecules impinge against the wing with slower moving molecules below creating a higher pressure than that due to faster moving molecules above, leading to Bernoulli's law, etc.; physics underlies higher level functioning,
- In terms of a *same-level explanation*: because the pilot is flying it, and she is doing so because the airline's timetable dictates that there will be a flight today from Madrid at 16h35 to Granada at 17h40,
- In terms of a *top-down explanation*: because it is designed and manufactured to fly! This was done by a team of highly trained engineers, in a historical context of the development of metallurgy, combustion, lubrication, aeronautics, control systems, computer aided design, etc., and in an economic context of a society with a transportation need and complex industrial organisations able to mobilise all the necessary resources for design and manufacture. It also occurred because individuals had the passion to make it happen.

These are all true explanations *that are simultaneously applicable*. The higher level explanations rely on the existence of the lower level explanations in order that they can succeed, but they are of a quite different nature than the lower level ones, and are neither reducible to them nor dependent on their specific nature. The system cannot exist and function unless *all* these levels of causation are effective.

6. Living systems are structured as (a) feedback control systems (b) that can learn (c) by capturing, storing, recalling, and analysing information. This involves (d) pattern recognition and (at the conscious levels) (e) implementation of predictive models based on (f) abstraction and symbolic representation and manipulation. It is these capacities that make the difference between complicated and complex systems (Ellis 2002a). They enable strongly emergent phenomena such as the functioning of cells (Harold 2001), recognising voices and faces, the existence of the rules of chess and the resulting strategies of chess players, as well as social institutions such as money and exchange rates.

There is no implication here as to how the information is stored (it might for example be encoded in particular atomic or molecular energy levels, sequences of building block molecules, synaptic connection patterns, in books, or in computer memories). Higher level behaviour is based on throwing away vast amounts of information: selecting what is relevant from a vast flow of incoming information, storing it, analysing it in a broad existential context, differentially amplifying it, and utilising it in feedback control systems that give higher level behaviour its teleological nature, in effect comprising causal models of the system and its environment in relation to desired goals.

Here we see non-material features such as concepts, information, and goals having causal effects in the material world of forces and particles, which means they have an ontological reality. We must assign a reality to all features that demonstrably causally affect the world of matter and particles. These include human conceptual schemes, plans, intentions, and emotions, as well as socially constructed features such as chess rules and prices. It must be emphasized here that *a concept is not the same as any physical configuration or entity*: rather it is an abstract entity that can be characterised as a socially realised equivalence class of physical representations, and is not identical to any particular physical representation in this class (a Jumbo Jet can be represented in a photograph, in speech, in written text, in a computer digital image, in CAD files, in a brain state, and so on; the concept is the same, but the representation varies).

7. Emergence takes place in, and partly enables, a context of multiple natures of existence relating to (a) particles and fields (the material world), (b) possibility landscapes characterising possible existence and changes of state (controlled by the laws of physics), (c) human ideas, goals and intentions, emotions, and social constructions, and (d) platonic mathematical properties and objects (Popper and Eccles 1977, Penrose 1997, Ellis 2003). In such an analysis, one assigns a reality to any feature that can be demonstrated to have a causal effect in the material world of particles, and must carefully distinguish between epistemology (knowledge) and ontology (existence). The structural relations that enable complex functionality must be assigned an ontological status, as well as the particles and forces that underlie them.

In philosophical terms, the outcome of emergent phenomena is *emergent pluralism* (Clayton 2003). What is not obvious is *whether true emergence is ever possible:* that is the creation through physical and biological processes of completely new types of structure and information without any kind of precursor - the creation of a completely new kind of order, or whether emergence in the physical world (which undoubtedly happens) is rather just the realisation of pre-existing potential and hence not a truly creative event. Complex objects are certainly preceded by the possibility of their existence, that is, their pre-image exists before them in a possibility space (otherwise they could not come into existence), see Ellis 2002b. The philosophical implications are unclear.

We now turn to looking at specific aspects in more detail.

2 Hierarchy and Top-down Action

The first key to handling complexity is *hierarchical physical structuring and function* (Simon 1962, Flood and Carson 1990, Peacocke 1983), its functioning involving the combination of *bottom-up* and *top-down action* (Campbell 1974) in the hierarchy of structure**.**

2.1 The nature of hierarchy and modularity

A hierarchy represents a decomposition of the problem into constituent parts and of processes into sub-processes to handle each of these sub-problems, each sub-process requiring less data and more restricted operations than the problem as a whole (Simon 1962, 1982). The levels of a hierarchy represent *different levels of abstraction*, each built upon the other, and each understandable by itself. *Emergent order* results; the behaviour of the whole is greater than the of the sum of its parts, and cannot even be described in terms of the language that applies to the parts.

The success of hierarchical structuring depends on implementing modules to handle lower-level processes and on integration of these modules into a higher-level structure (for example, atoms comprising molecules and cells comprising a living being). Complex structures are made of modular units with abstraction, encapsulation, and inheritance (Booch 1994 and references therein). This structuring enables the modification of modules and re-use for other purposes.

An abstraction denotes the essential characteristics of an object that distinguishes it from all other kinds of objects. It focuses on the outside view of the object, and so serves to separate its essential behaviour from its implementation; it emphasises some of the system's details or properties, while suppressing many others. Information is thrown away by the billion bits all the time, because all the micro-alternatives can neither be examined nor controlled. The high-frequency dynamics of the internal structures of components (relating internal variables) contrasts with the low-frequency dynamics of interactions amongst components (relating external variables).

Encapsulation is when the internal workings are hidden from the outside, so internal procedures can be treated as black-box abstractions. A key point is that no part of any complex system should depend on the internal details of any other part - system functionality only specifies each component's function, leaving it to the object to decide how to do it . *Inheritance* is when specialised modules (forming a sub-class) preserve most or all of the functions of the super-class, but with extra specialisation or further properties built in. This corresponds to fine-tuning the modules to more handle more specialised problems (for example generalised cells specialise to form neurons).

A key feature is that *compound objects (combinations of modules) can be named and treated as units by appropriate labelling.* This leads to the power of abstract symbolism and symbolic computation.

2.2 Coherent higher level action

In general many lower level states correspond to a single higher level state, because a higher level description $\boldsymbol{H_1}$ is arrived at by ignoring the micro-differences between many lower level states $\boldsymbol{L_i}$, and so throwing away a vast amount of lower level information (*coarse graining*). For example numerous microstates of particle positions and velocities correspond to a single macro-state of nitrogen gas with a pressure of one bar and temperature of 20K in a volume of 1 litre: see Figure 4a.

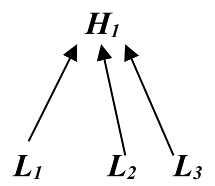

Figure 4a: Lower level states all corresponding to the same higher level state.

The number of lower level states corresponding to a single higher level state determines the entropy of that state. This is lower level information that is hidden in that higher level view. ***Hence:*** specification of a higher level state $\boldsymbol{H_1}$ determines a family of lower level states $\boldsymbol{L_i}$, any one of which may be implemented to obtain the higher level state: see Figure 4b.

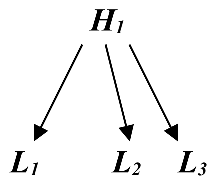

Figure 4b: Specifying a higher level state specifies a whole family of lower level states.

The specification of higher level structure may be broad (attainable in a very large number of ways, e.g. the state of a gas) or detailed (defining a very precise structure, e.g. the currents in a VLSI chip in a computer). In the latter case both description and implementation require far more information than in the former.

The system dynamics (causal interactions due to physical interactions between the components) acts on each lower level state $\boldsymbol{L_i}$ to produce a new lower level states $\boldsymbol{L'_i}$. Two major cases arise:

(a) Different lower level realisations of the same higher level initial state result, through microphysical action, in different higher level final states: see Figure 5a.

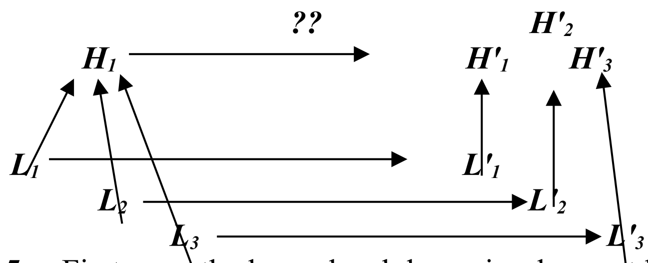

Figure 5a: First case: the lower level dynamics does not lead to coherent higher level dynamics.

Here there is no coherent higher level action generated by the lower level actions; the higher level result is unpredictable. Chaotic systems (with highly sensitive dependence on initial conditions) are examples.

(b) Different lower level realisations of the same higher level initial state result, through microphysical action, in the same higher level final state (up to the accuracy of the higher level description utilised), see Figure 5b.

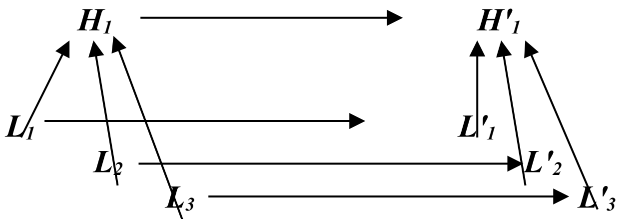

Figure 5b: Second case: the lower level dynamics leads to coherent higher level dynamics.

A coherent higher level action results from the lower level action (perhaps in a statistical sense). An example is gas in a container that is initially hot in one region and cooler elsewhere; diffusion will result in a final state of uniform temperature. Both the initial and final states can be realised through numerous micro-states. It is possible that $\boldsymbol{H_1 = H'_1}$: then we have an equilibrium state of the system (in the case of the gas, this will be so if the initial state is one of uniform temperature).

2.3 Top-down action underlying coherent higher level properties

Top-down action is when the higher levels of the hierarchy causally effect what happens at the lower levels in a coordinated way. Micro-causation occurs in the context of the structure given, and it can happen that each lower level state corresponding to a specific initial higher level state results in the same final upper level state, so that every lower level implementation of the initial higher level state gives the same higher level outcome: see Figure 6a.

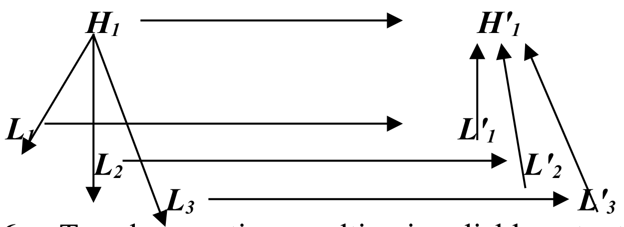

Figure 6a: Top-down action resulting in reliable output from a higher level initial state.

Then consistent behaviour occurs at the higher level, regarded as a causal system in its own right - there is now effective higher level autonomy of action, enabled by coordinated lower level action, see Figure 6b. An example is pressing a key on a computer (H_1 is the computer with the key pressed), resulting in a letter being displayed on the screen (H'_1 is the computer with the key pressed and the letter displayed on the screen). The higher level action is the same whatever detailed (lower level) electron motions result in the computer circuits. The lower level action and resultant final higher level state would be different if the higher level state were different (for example if a different key were pressed).

$$\boldsymbol{H_1} \longrightarrow \boldsymbol{H'_1}$$

Figure 6b: The resultant higher level action regarded in its own right; it can be analysed without knowledge of the underlying lower-level interactions.

Boundary effects as well as structural relations effect top-down action. The higher level action is effective by coordinating actions at the lower levels. Whether this reliably happens may depend on the particular coarse-graining (i.e. higher level description) chosen. Describing the higher level change at the lower level is not desirable because it is not illuminating ("10^{24} nuclei and associated electrons moved simultaneously in a coordinated manner so as to decrease the volume available to 10^{23} gas molecules", requiring about10^{36} bits of information for a full description, is actually "the piston moved and compressed the gas") and may even not be possible. Indeed this is the reason that we develop and use higher level language and mathematical descriptions. These may be employed whether or not we understand the lower level causation.

Multiple top-down action as well as bottom-up action *enables self-organisation of complex systems*

, as it enables higher levels to co-ordinate action at lower levels, and so gives them their causal effectiveness.
Top-down action is prevalent in the real physical world and in biology, because no real physical or biological system is isolated; through this process, information flows from the higher to the lower levels. Examples are as follows:

A: A gas in a cylinder with piston. The cylinder walls together with the piston position determine the gas pressure and temperature. Both are macro concepts which make no sense at the micro level.

B: Nucleosynthesis in the early universe. The creation of light elements in the early universe is controlled by nuclear reaction rates and the slow decay rate of the neutron, together with the expansion rate of the universe. The latter is determined by the cosmology through the Friedmann equation. The light element production is different if the universe expands differently, and the expansion rate depends on the kinds of matter present then in bulk, consequently we can use the light element abundances to determine the amount of baryons in the universe (Rees 2001).

C: Local physics experiments. Top-down action occurs in the quantum measurement process, because the experimenter determines the range of possible outcomes of the experiment by her choice of apparatus set-up. Also, top-down action from the universe itself determines the local arrow of time in all local physics, and hence in chemistry and biology, for it is not determined by the fundamental physical laws (Ellis 2003).

D: Determination of DNA codings through evolution. The development of DNA codings (the particular sequence of bases in the DNA) through an evolutionary process which results in adaptation of an organism to its ecological niche is a top-down process proceeding from the environment to the DNA (Campbell 1991). For example, a polar bear has genes that cause its fur to turn white, reflecting its adaptation to the Antarctic, as opposed to the gene sequence in Canadian bears that turns them brown because they have adapted to the Canadian forest. This is a classical case of top-down action from the environment to detailed biological microstructure - through the process of adaptation, the environment (along with other causal factors) fixes the specific DNA coding. There is no way you could ever predict this coding on the basis of biochemistry or microphysics alone.

E: Biological development through reading of DNA codings. The central process of developmental biology, whereby positional information determines which genes get switched on and which do not in each cell, so determining their developmental fate (Gilbert 1991, Wolpert 1998) is a top-down process from the developing organism to the cell, largely based on the existence of gradients of positional indicators in the body. This essentially tells each cell where it is in the developing body and hence what kind of cell it should be (forming blood, bone, hair, neurons, etc).
Without this feature organism development in a structured way would not be possible. Thus the functioning of the crucial cellular mechanism determining the type of each cell in a body is controlled in an explicitly

top-down way. However the gene does not function as an automaton following a fixed program (Fox Keller 2000); it has its own structural regularities and program as well as that determined by genes.

F: Mind on body.

Top-down action occurs from the mind to the body and thence into the physical world. Movement of a hand is an example where many millions of atoms move in response to a decision made, conveyed to the specific muscle structure by the central nervous system (Guyton 1977, Rhodes and Plfanzer 1989). Top-down action by the mind on health occurs through neurotransmitters acting on the immune system (Sternberg 2000).

G: The effect of human intentions.

When a human being has a plan in mind (say a proposal for a bridge being built) and this is implemented, then enormous numbers of micro-particles are moved around as a consequence of this plan and in conformity with it. For example, this occurs in the making of bridges and aircraft and the detonation of a nuclear bomb.

Social constructions such as chess rules are socially embodied and are causally effective. Imagine a computer or alien analysing a large set of chess games and deducing the rules of chess (i.e. what moves are allowed and what not); it would know these are inviolable rules but have no concept of their origins, i.e. whether they were implied by modification of Newton's laws, some potential fields that constrain the motion of the chess pieces, or a social agreement that restricts their movement and can be embodied in computer algorithms. Note that the chess rules are not just mind states – they exist independent of any particular mind or physical representation. Other examples are an economy and associated exchange rates; money is a physical embodiment of this order while the exchange rates are socially embodied but are also embodied for example in ink on newspaper pages and in computer programmes stored in computer memories and utilised by banks.

Thus in the real world, the detailed micro-configurations of many objects (which electrons and protons go where) is in fact to a major degree determined by the macro-plans that humans have for what will happen. This means the structural hierarchy, interpreted as a causal hierarchy, bifurcates (Murphy and Ellis 1995) as shown in Figure 7.

Hierarchical structure: 2

	Ethics
Cosmology	*Sociology*
Astronomy	*Psychology*
Geology	*Physiology*
Materials	*Biochemistry*

Chemistry

Physics

Figure 7. Hierarchy of causal relations. ***The hierarchy of physical relations (Figure 1) extended to a branching hierarchy of causal relations***

. The right hand branch involves goals and conscious choices, which are causally effective; no such effects occur in the left hand branch.

The right hand side is to do with choice of goals that lead to actions. Ethics is the high-level subject dealing with the choice of appropriate goals. Because it constrains the lower level goals chosen, and thence the resulting actions, ethics is causally effective in the real physical world. For example, a prison may or may not have present in its premises the physical apparatus of an execution chamber; whether this is so or not depends on the ethics of the country in which the prison is situated.

3 Feedback Control and Information

The second key to emergence of truly complex properties is the role of hierarchically structured information in setting goals in *feedback control systems,* implemented through their highly coordinated physical structure, as for example in human physiology (Guyton 1977, Rhodes and Plfanzer 1989).

3.1 Feedback control

The central feature of organised action in complex systems is *feedback control* (Beer 1966, Milsum 1966), whereby setting of goals results in specific actions taking place that aim to achieve those goals. A comparator compares the system state with the goals, and sends an error message to the system controller if needed to correct the state by making it a better approximation to the goals (Figure 8). Classic examples are controlling the heat of a shower, the direction of an automobile, or the speed of a steam engine. One should note that the linkages to the comparator and thence to the controller are *information linkages* rather than power and/or material linkages like that from the activator to the system (the information flow will use a little power, but only that needed to get the message to where it is utilised).

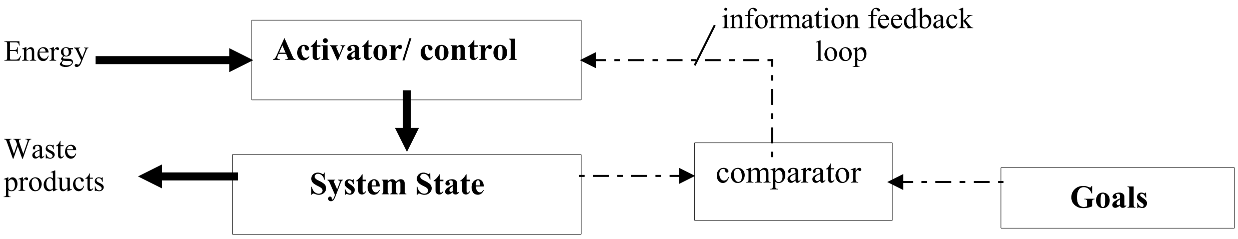

Figure 8: The basic feedback control process. The second law of thermodynamics requires energy input and heat output in active processes, which must occur then in an open system.

Thus it is here that the *key role of information* is seen: *it is the basis of goal choice in living systems* (and artefacts that embody feedback control). The crucial issue is, what determines the goals: where do they come from? Two major cases need to be distinguished.

3.2 Homeostasis

There are numerous feedback control systems at all structural levels in all living cells, plants, and animals (Milsum 1966) that automatically (i.e. without conscious guidance) maintain homeostasis - they keep the structures in equilibrium through multiple feedback systems that fight intruders (the immune system) and control energy and material flows, breathing and the function of the heart, body temperature and pressure, etc. They are effected through numerous enzymes, anti-bodies, regulatory circuits of all kinds (for example those that maintain body temperature and blood pressure). Indeed Guyton suggests that all the major human physiological systems can be viewed as homeostasis systems (Guyton 1977).

The inbuilt goals that guide these activities are implicit rather than explicit, for example the temperature of the human body is maintained at 98.4F with great accuracy but without that figure being explicitly pre-set in some control apparatus; nevertheless certainly these goals are identifiable and very efficiently attained. In living systems, they have developed through the course of time through the processes of evolution, and so are historically determined in particular environmental context. In manufactured artefacts, the goal may be explicitly stated and controllable (e.g. the temperature setting of a thermostat).

It is important to realise that *not only are the feedback control systems themselves emergent systems*, but also *the implied goals are emergent properties that guide numerous physical, chemical, and biochemical interactions in a teleological way*. They represent distilled information about the behaviour of the environment in relation to the needs of life, and so they represent implicit information processing by the organism. Information storage and recognition occurs and allows adaptive responses already at the level of supra-molecular chemistry (Lehn 1995). Neurons are specifically structured to process information (Rhodes and Plfanzer 1989) and underlie the instinctive (inbuilt) behaviour of animals and humans.

3.3 Goal seeking

However at higher levels in animals and humans, important new features come into play: there are now explicit behavioural goals, that are either learnt or are consciously chosen. *It is in the choice of these goals that explicit information processing plays a vital role*. Information arrives from the senses and is sorted and discarded or stored in long term and short term memory, representing past situations and causal patterns. Conscious and unconscious processing of this information in the context of the current environmental and social situation sets up a goal hierarchy which then controls purposeful action through feedback control loops in the human body that are hierarchically structured, with maximum decentralisation of control from the higher to the lower levels, as is required both in order to handle requisite variety and the associated information loads (Beer 1972), and for maximal local efficiency (ability to respond to local conditions). This is reflected in societal feedback loops that underlie welfare in society (Ellis 1984,1985).

A: Memory and learning. *Memory* allows both the long term past and the immediate environmental context to be taken into account in choosing goals, providing historical information used to shape these goals in conjunction with present data (e.g. remembering that an individual let us down in important ways years ago). *Learning* allows particular responses to develop into an automatic skill, in particular allowing responses to become inbuilt and so able to be rapidly deployed (e.g. walking, driving a car, sports moves, and so on).

B: Analysis and prediction. The brain is continually capturing, storing, recalling, and analysing information; *inter alia*, this involves pattern recognition and selection of what is important, discarding most of the rest, and using the information retained to implement predictive models guided by expectations of what is `normal' in a given context; in particular, modelling how other people may be expected to behave (Donald 2001).

A key issue is how context influences behaviour; one has to continually choose which predictive model to use in a given context. This choice is guided by higher level analysis. Implicit or explicit goals guide all of this mental activity, and inform and guide strategies chosen to reach the goals.

C: Symbols and social behaviour. At the highest level, the process of analysis and understanding is driven by the power of images (Boulding 1961) and symbolic abstraction (Deacon 1997), codified into language, embodying both syntax and semantics, and other social creations such as specialised roles in society and the monetary system, together with higher level abstractions such as mathematics, physical models, and philosophy. The brain coevolves with culture which largely shapes the brain according to distributed symbolic systems (Donald 1991) that enable shared experience and understanding to be causally effective. Human brains do not develop and function in isolation: the causative whole is a social network (Donald 2001), without which language and symbolism could not evolve. The meta-question of how context influences behaviour is guided and constrained by a system of ethics based on an overall world-view associated with meaning. This will be encoded in language and symbols.

3.4 Information origin and use

Responsive behaviour thus depends on purposeful use of information: storage, transmission, recall, and assessment to control physical functions in accord with higher level goals. Current information received from the senses is filtered against a relevance pattern, the irrelevant being discarded, the significant being stored in compressed form, and the important being selectively amplified and used in association with current expectations to assess and revise immediate goals. Recall of past events (long term memory) allows a non-local (in time) kind of causation that enables present and future behaviour to be based on interpretations of long past events. Expectations are based on contextually based causal models grounded in past experience, constantly revised on the basis of newer experience and information. Thus feedback control systems based on sophisticated interpretations of present and past data enable purposeful (teleological) behaviour. This is the way the hierarchy of goals is causally effective in the physical world, being effected through the nervous system. The whole is based on a symbolic representation of reality.

The goals, symbols, and expectations are all strongly emergent phenomena that are causally effective but are certainly not derivative from physics or chemistry. There can be no direct connection between micro-physics and choice of these goals and strategies – they are determined at higher causal levels. They exist as non-material effective entities, created and maintained through social interaction and teaching, and are codified in books and sometimes in legislation. Thus while they may be represented and understood in individual brains, their existence is not contained in any individual brain. They certainly are not equivalent to brain states, which are just one of many possible forms of embodiment of these features.

3.5 The full depth of humanity

The emergent qualities envisaged must entail the full depth of humanity, precisely because we do indeed know these qualities exist. Key features are characterised by Rescher (1990) as

1. *Intelligence* (assessing information and holding beliefs about the world and one's place in it),
2. *Affective* (evaluating developments as good or bad and driven by ideals),
3. *Agency* (autonomous agents pursuing goals proceeding from within their own thought),
4. *Rationality* (acting in a reasoned manner),
5. *Self-understanding* (conceiving of oneself as an intelligent free agent),
6. *Self-esteem* (valuing oneself),
7. *Mutual recognizance* (acknowledging other persons and valuing them).

They extend to the best literature and art in the world - Shakespeare, Dostoyoevsky, Michaelangelo, Rembrandt, etc., as well as the heights of generosity, love, and self-sacrificial (kenotic) moral endeavour - Ghandi, Martin Luther King, Desmond Tutu, etc. (cf. Murphy and Ellis 1995). All these higher qualities emerge from their physical foundations through the mind, in turn determined largely by its social interactions (Siegel 2001).

Both these qualities and the interactions that lead to them are thus causally effective, and any theory of emergence must recognise this and take it into account. This requirement strongly contradicts the attitude that anything which does not fit into a restrictive strong reductionist framework must be either denied existence or declared to have no value (see Donald 2001 for analysis and refutation of views denying the causal effectiveness of consciousness).

4 Evolution and Developmental processes

Deve
lopment of complexity in living systems requires both
evolutionary processes acting over very long time periods and developmental processes acting over much shorter times.

4.1 Darwinian Evolution and Developmental Processes

The historical rise of these complex emergent features on a planet that comes to existence in the expanding universe occurs through spontaneous self-organisation of structures (Morowitz 2002), with gravitational attraction leading to planets (Rees 2001), molecular and chemical evolution leading to living cells and life, and then a Darwinian process of natural selection acting on living systems to create high level functionality (Campbell 1991). This process develops and stores genetic information in the form of a sequence of bases in DNA characterising the nature of the biological family involved. Information stored is selected on basis of evolutionary adaptation to specific environmental niches.

The process can be regarded as selective amplification of favourable lower level causal processes (Murphy 2003).

As mentioned above, the embodiment of this complexity in living individuals as they develop from a single cell to a multi-cellular organism with 10^{13} cells occurs through a developmental process which uses positional information to control the reading of this genetic information and so determine cell fate, using morphogen gradients and environmental information to structure the developing organism (Gilbert 1991, Wolpert 1998). Information from the external and internal environment is crucial in this process of cell development (Harold 2001).

4.2 The Brain: both combined

When utilising genetic information in each individual for brain development,

principles of Darwinian natural selection apply in the developmental process (`Neural Darwinism', Edelmann 1989) controlling detailed neural connections of each brain. This is necessary both because the stored information is far too little to control brain development by itself - the Human Genome Project tells us there are about 45,000 genes in each human cell, but there are 10^{13} cells and 10^{11} neurons in a human being, with about 10^{14} synaptic connections-

and because this allows the brain to optimally adapt to the local environment.

In essence, neuronal connections are established on broadly structured basis that is largely random at a detailed level; then those connections that are useful are strengthened while those of little value are allowed to decay and those of negative value are killed off. The key issue then is what provides the *fitness characterisation* determining whether particular connections are strengthened or not (*the value system,* Edelmann and Tononi 2001). The plausible answer is the *signals provided by the set of primitive emotional functions*, each characterised by specific neurotransmitters such as dopamine, as described by Panksepp (1998): “The neurobiological systems that mediate the basic emotions … appear to be constituted of genetically coded, but experientially refined executive circuits situated in subcortical areas of the brain which can coordinate the behavioral, physiological and psychological processes that need to be recruited to cope with a variety of survival need (i.e., they signal evolutionary fitness issues).... The various emotional circuits are coordinated by different neuropeptides, and the arousal of each system may generate distinct affective/ neurodynamic states”. The proposal here is that they also help govern the microstructure of neural connections by emitting neurotransmitters (Ellis and Sternberg 2003).

This makes explicit the way in which emotions can guide the emergence of intellect through identified physical processes. They provide the evaluation functions by which the processes of neural Darwinism determine whether some particular set of neural connections are fit to survive or not. The basic emotional systems active in this way are the following:

1: general motivation: seeking/expectancy and associated satisfaction/ dissatisfaction
2: rage/anger
3: fear/anxiety
4: lust/sexuality
5: care/nurturance
6: panic/separation
7: play/joy

8: rank/dominance/status/attachment
9: social approval/disapproval.

The first seven are clearly identified by Panksepp (1998), giving also associated key brain areas and neurotransmitters with the last two being plausible extras. In particular the foundation of learning on the basis of success or failure of one's endeavours is provided by the signals from the seeking system. This mechanism provides the basis for brain-culture co-evolution (Deacon 1997), the top-down view of which is described by Berger and Luckmann (1967) and the same-level view by Donald (2001).

5 Types of emergence

Different levels of emergence have been suggested by Terrence Deacon (Murphy 2003). The following is a different proposal for characterising such levels, based on the above analysis of complex systems:

Level 1 Emergence: *Bottom up action leads to higher level generic properties but not to higher level complex structures or functions,* e.g. it gives a determination of generic properties of gases, liquids, and solids: the gas law, conductivity, heat capacity, etc.(Goodstein1985); statistical physics applies, and entropy represents hidden information due to coarse graining. This kind of emergence leads to coherent upper level action, and reduction is in principle possible. However reduction fails in practice, not just because of (i) the inability to derive in this way the full complexity of behaviour of substances as simple as water, but also because (ii) the arrow of time/entropy problem is unresolved (Zeh 1989, Halliwell et al 1994), (iii) quantum measurement issues are unresolved (Penrose 1989), and (iv) divergences and incorrect predictions of the value of the cosmological constant mean we do not properly understand quantum field theory. It is also challenged fundamentally by R B Laughlin's claim (v) that all elementary particle properties may be emergent (Laughlin 1999).

Level 2 Emergence: *Bottom up action plus boundary conditions lead to interesting higher level structures not directly implied by the boundary conditions* – as for example in (i) sand piles, (ii) the reaction diffusion equation, (iii) magnetic domains, (iv) convection patterns, (v) cellular automata, (vi) gravitational structure formational in the expanding universe, (vii) inorganic and organic molecules. This increases the level of complexity above what was input to the system, and so leads to the emergence of structures that are not reducible; but despite the immense combinatorial possibilities (Scott 1995) they are not truly complex, as they do not have the key element of goal-seeking that characterises living systems. However they may sometimes be an important initial step on the way towards evolution of genuinely complex systems (e.g. in developmental biology processes). Standard statistical physics does not apply; one goes beyond it to critical phenomena (Binney et al 1993, Bak 1997), chaos theory (Bai-Lin 1984, Thompson and Stewart 1987), kinetic self-organisation (Peacocke 1983), and basic chemical structure (Atkins and Jones 2002), but these interactions are not directed by information or goals.

Level 3 Emergence: *Bottom up action in highly structured system leads to existence of feedback control systems at various levels* and so to coordinated responses that allow meaningful top-down action, and hence to *coherent non-reducible upper level action directed by implicit inbuilt goals*. Thus these systems enable an element of teleonomy – of goal-seeking representing an effective physical effect of information. However the inherited goals guiding these feedback systems are independent of individual life history, being pre-determined by the evolutionary history of the species - no learning occurs. This allows adaptive behaviour, but based on pre-set rules. Examples are processes in all living cells (Harold 2001) and in plants (Bidwell 1979). This information-based functioning starts at the supra-molecular level (Lehn 1995).

Level 4 Emergence: Here there is additionally to Level 3, *existence of feedback control systems directed by explicit goals related to memory, i.e. influenced by specific events in the individual's history*. Learning occurs based on individual experience and some form of stored memory, allowing adaptive behaviour responding to historical events. This is presumably always related to some form of consciousness, leading to goal choice related to the remembered past. This occurs in animals (Slater 1999), for example when a dog responds to its feeding bowl or leash, through the integrated complexity of its hierarchy of control systems and support systems (Randall 2002). This kind of emergence extends to complex social interactions as in much animal behaviour (Slater 1999), including significant forms of communication.

Level 5 Emergence: In addition to level 4, *some goals are explicitly expressed in language systems and/or are determined by symbolic understanding or complex modelling of the physical and social environment*. Here there is additionally to individual consciousness, the capacity to handle *symbolic systems* with both syntax and semantics (Deacon 1997), presumably arising in conjunction with the capacity for self-consciousness reflection, and - integral to this - the feature of *distributed consciousness*, with the development of brains and culture occurring in interaction with each other (Berger and Luckmann 1967, Donald 1991, 2001). On earth, this only occurs in the case of humans, enabled by the structure of the brain (Kingsley 1996) and all its supporting mechanisms (Rhoades and Pflanzer 1989). This enables creation of artifacts (conscious design) and transcendence of specific given conditions by changing the environment or the context of action. Note that I am presuming in this article the effectiveness of consciousness, as discussed by Donald (2001).

6 The challenge to physics

Emergent effects are determined by a combination of chance (historical contingency) and necessity (physical laws), but there is additionally a role of conscious choice in level 4 and 5 emergence. This is a key feature in our analyses of the world around us - without conscious choice, the attempt to understand does not make sense. We can only believe the outcome of our arguments and analyses if we have the ability to relate them to evidence, logic, and coherence. This is a high level emergent activity by which we are able to weigh the evidence and make a choice; if we cannot make a choice, we cannot weigh the evidence. Thus free will is necessary for scientific activity to occur, and I am assuming it exists. Total reductionism that denies free will also denies the ability to reason logically and arrive at a valid conclusion, and so undermines science itself.

The issue facing scientists is, are we trying to construct a causally complete theory of interactions that affect events in the physical world? If so, then humans must be included in the causal system (e.g. taking into account the fact that physicists carry out experiments) and the emergence of all the higher order phenomena mentioned above must be taken into account. If not, we will necessarily have a causally incomplete theory, and must not pretend it can satisfactorily link human behaviour to physics and chemistry.

The challenge to physics is that the higher levels are demonstrably causally effective, in particular consciousness is causally effective; but conscious plans and intentions and emotions are not describable in present day physical terms. Thus physics has two choices: either

1. Extending its scope of description to encapsulate such higher level causal effects, for example including new variables representing thoughts and intentions and so enabling it to model the effects of consciousness and its ability to be causally effective in the real physical world,

or

2. Deciding that these kinds of issues are outside the province of physics, which properly deals only with inanimate objects and their interactions. In that case physics must give up the claim to give a causally complete description of interactions that affect the real physical world.

Whichever option is adopted, the concept of a `theory of everything' as usually understood by physicists (a unified theory of fundamental forces and interactions such as String Theory, see e.g. Greene 1999) must be acknowledged to be a concept that cannot give a complete account of all causally effective aspects of the physical world, which includes the biological world. At the minimum physics has to be related somehow to the world of thoughts and feelings before it can make any claim to provide causal completeness – which presumably a truer `theory of everything' should do.

The key point is that human intentions and goals are not just convenient auxiliary variables that summarise physical microstates; rather they are essential variables in many causal processes. Without them we cannot adequately model causation involving human beings (for example we cannot predict whether a pair of spectacles or a Jumbo jet will be likely to emerge from a mental process). They are irreducible higher-level quantities that are clearly causally effective in the physical world.

Additionally, there is a major question to be answered by physics, whether based on a unified theory of interactions or not: namely, why does it allow the complexity examined in this paper to come into being? (Ellis 2003). Why does it satisfy the well-known series of anthropic constraints that allow life as we know it to exist? (Rees 2003, Tegmark 2003). Most such unified theories would not be physically able to underpin the complexity we observe in the real world. Thus there is a double relation of fundamental physical theory to the existence of intelligent life that needs clarification.

7 Conclusion

Reprise: I have given above a view of emergent complex systems where there are structuring relations, triggering relations as well as environmental influences and internal variables, summarised in Figure 9.

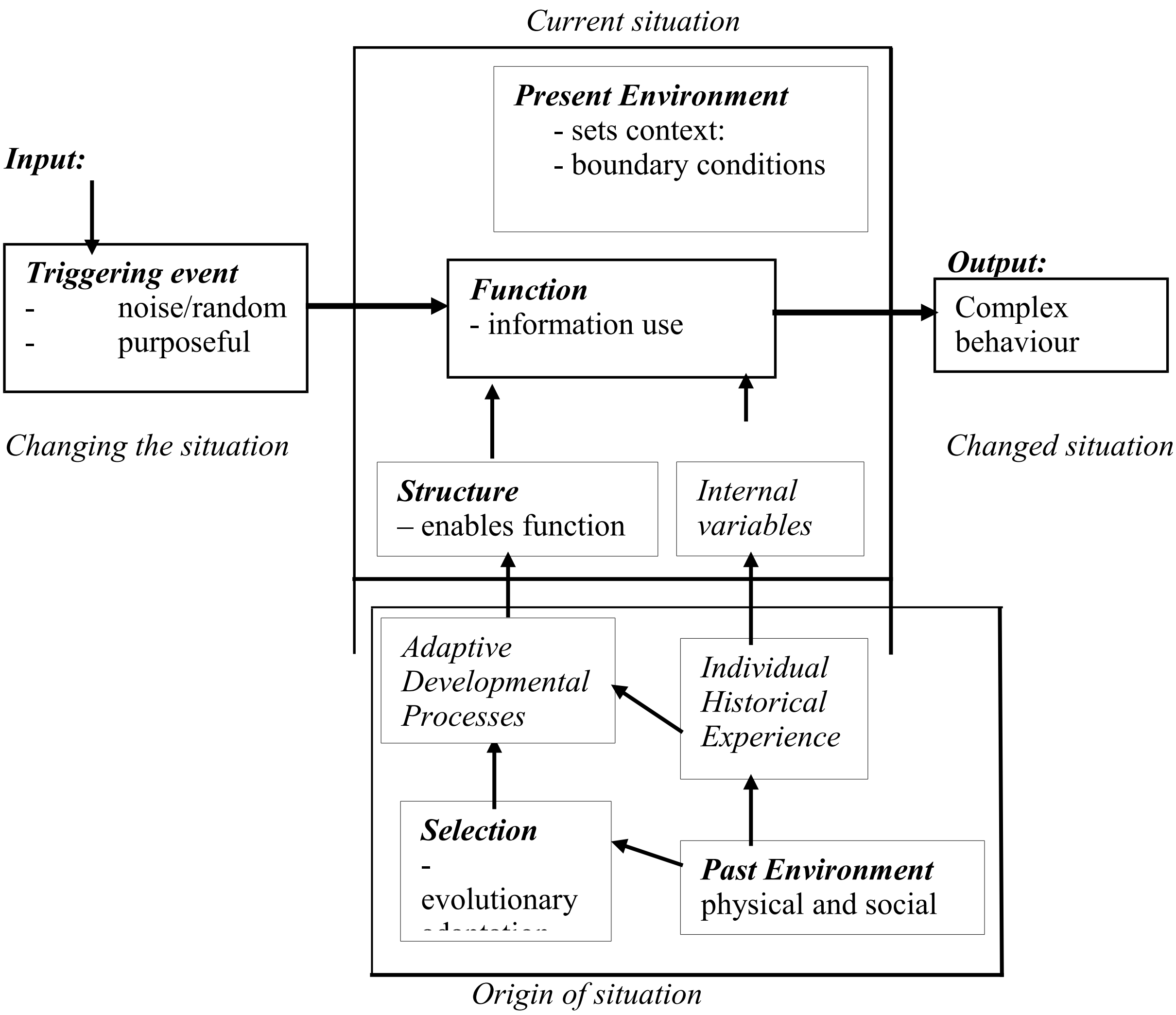

Figure 9: The system and its situation: contextual and triggering influences.

Function takes place in the context of a social and physical situation that, together with the values of internal variables, is the current operating environment. Structure is constant on the relevant timescale, enabling the input (triggering events that operate in the given situation – they are varying causal quantities) to have a predictable result. Thus function follows structure. The environment sets the boundary conditions and the internal variables (memory and learnt behaviour patterns) result from past experience. Noise or chance represents the effects of detailed features that we do not know because they are subsumed in the coarse graining leading to higher level descriptions of either the system or the environment. The system structure is determined by developmental processes that use genetic information, read in the context of the system-environment interaction occurring in the organism's history, to determine its structure. For example, genes develop a brain capacity to learn language that then results in adaptation of the brain to that specific language. The genetic heritage leading to this result is comes into being through evolutionary adaptation over very long timescales to the past environment. This language then forms the basis of complex symbolic modelling and associated understanding, taking place in a social context, that guides future actions. Thus human understanding of events and their meanings govern their actions, which then change the situation around them. Symbolic systems are causally effective.

Strong reductionist claims, usually characterised by the phrase `nothing but' and focusing only on physical existence, simply do not take into account the depth of causation in the real world as indicated above, and the inability of physics on its own to comprehend these interactions and effects. These claims represent a typical fundamentalist position, claiming a partial truth (based on some subset of causation) to be the whole truth and ignoring the overall rich causal matrix while usually focusing on purely physical elements of causation. They do not and cannot be an adequate basis of explanation or understanding in the real world. Consequently they do not represent an adequate basis for making ontological claims.

This paper has outlined a view of emergent reality in which it is clear that non-physical quantities such as information and goals can have physical effect in the world of particles and forces, and hence must be recognised as having a real existence (Ellis 2003). Associated with this there is a richer ontology than simple physicalism, which omits important causal agencies from its vision. That view does not deal adequately with the real world.

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